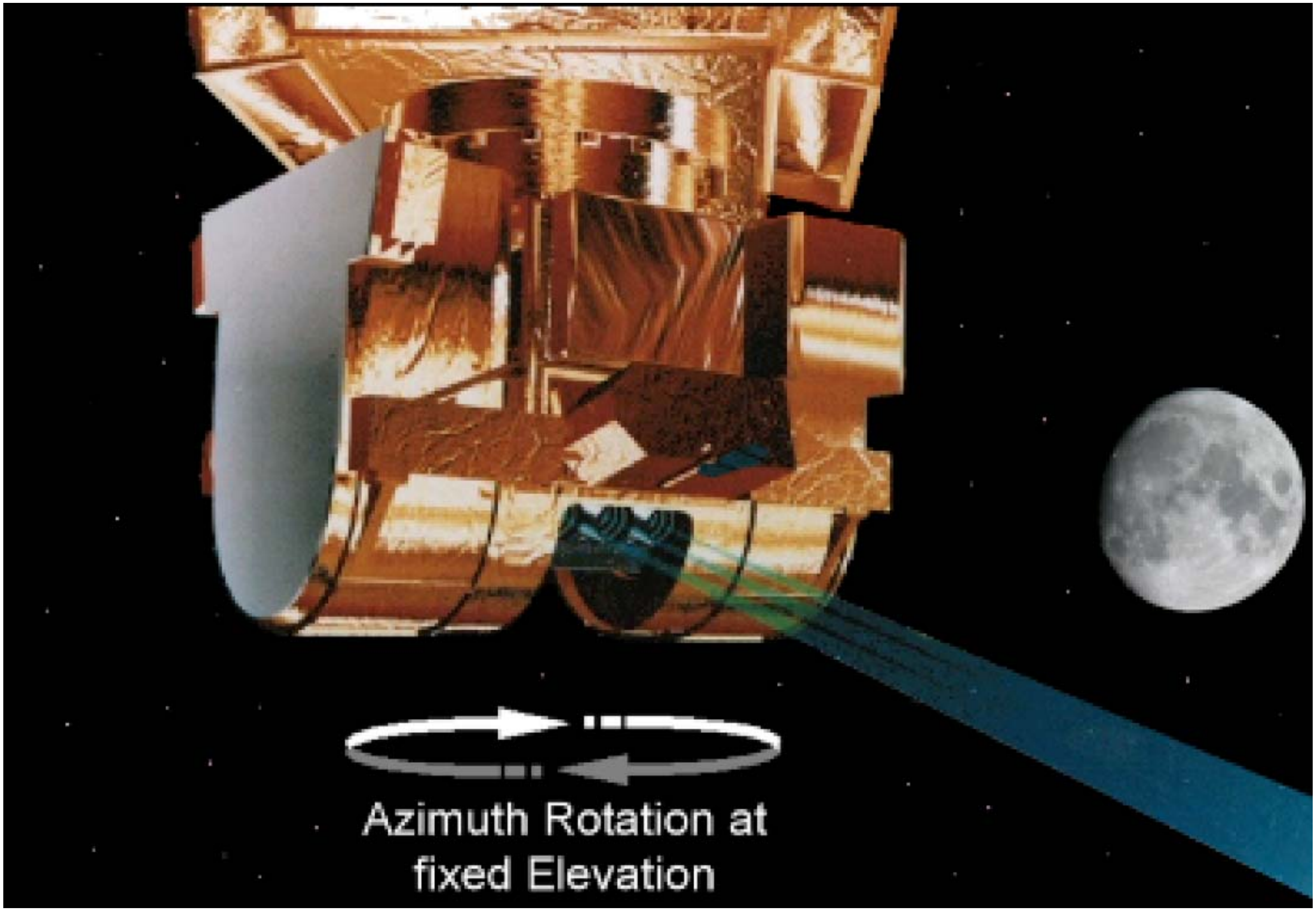
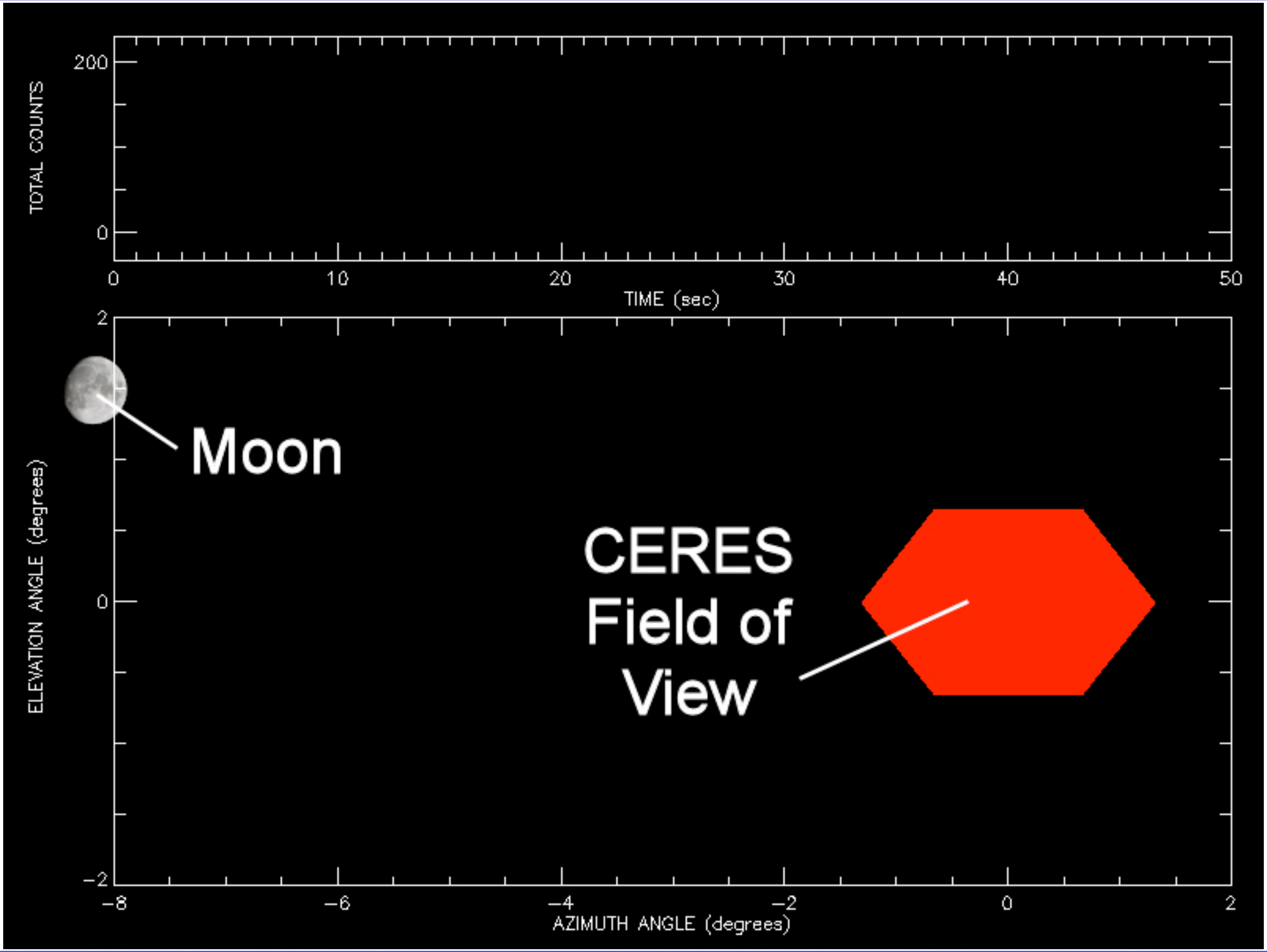
# Absolute Lunar Radiance Measurement Technique for CERES: Results and ERB Climate Stability Target Potential of the Moon

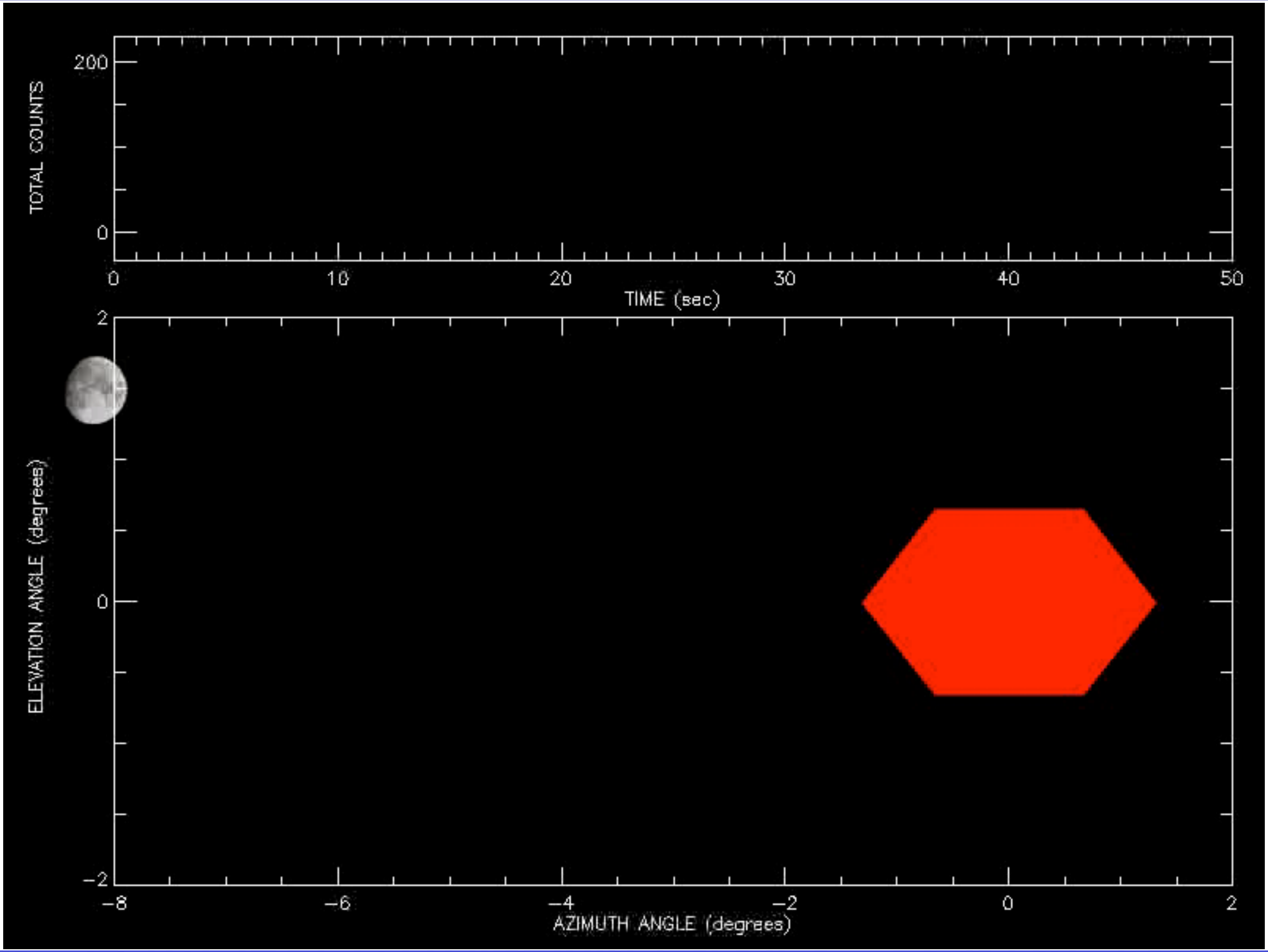

**Grant Matthews**

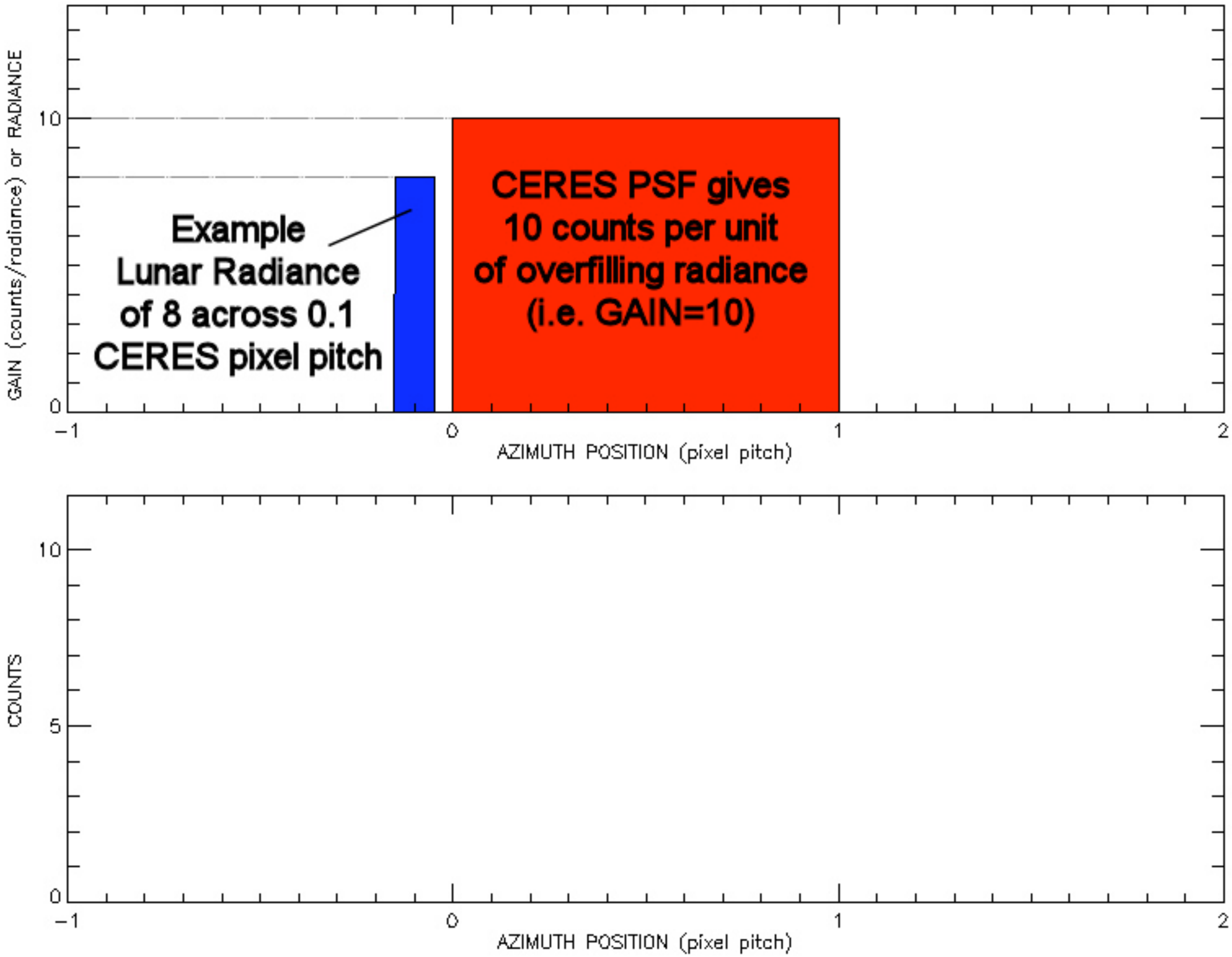
**Contributions from: Thomas C. Stone (USGS)**

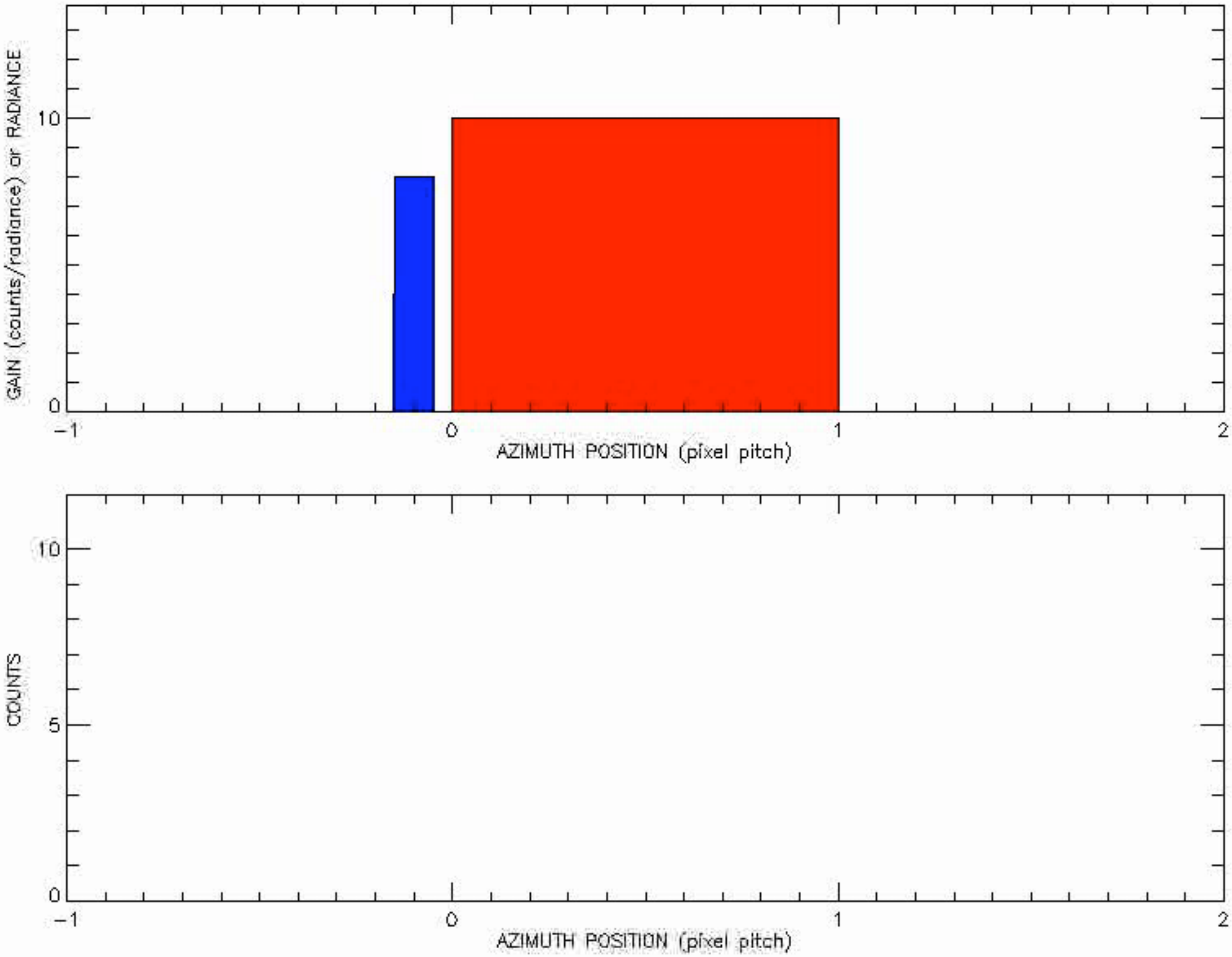
- Lunar Raster Scan Data
- Use of convolution integral technique
- Filtered radiance calculation
- Unfiltering Lunar Radiance to Irradiance
- Results
- The Moon as an ERB climate stability target
- Use of the technique to diagnose spectral darkening on future ERB instruments
- Summary

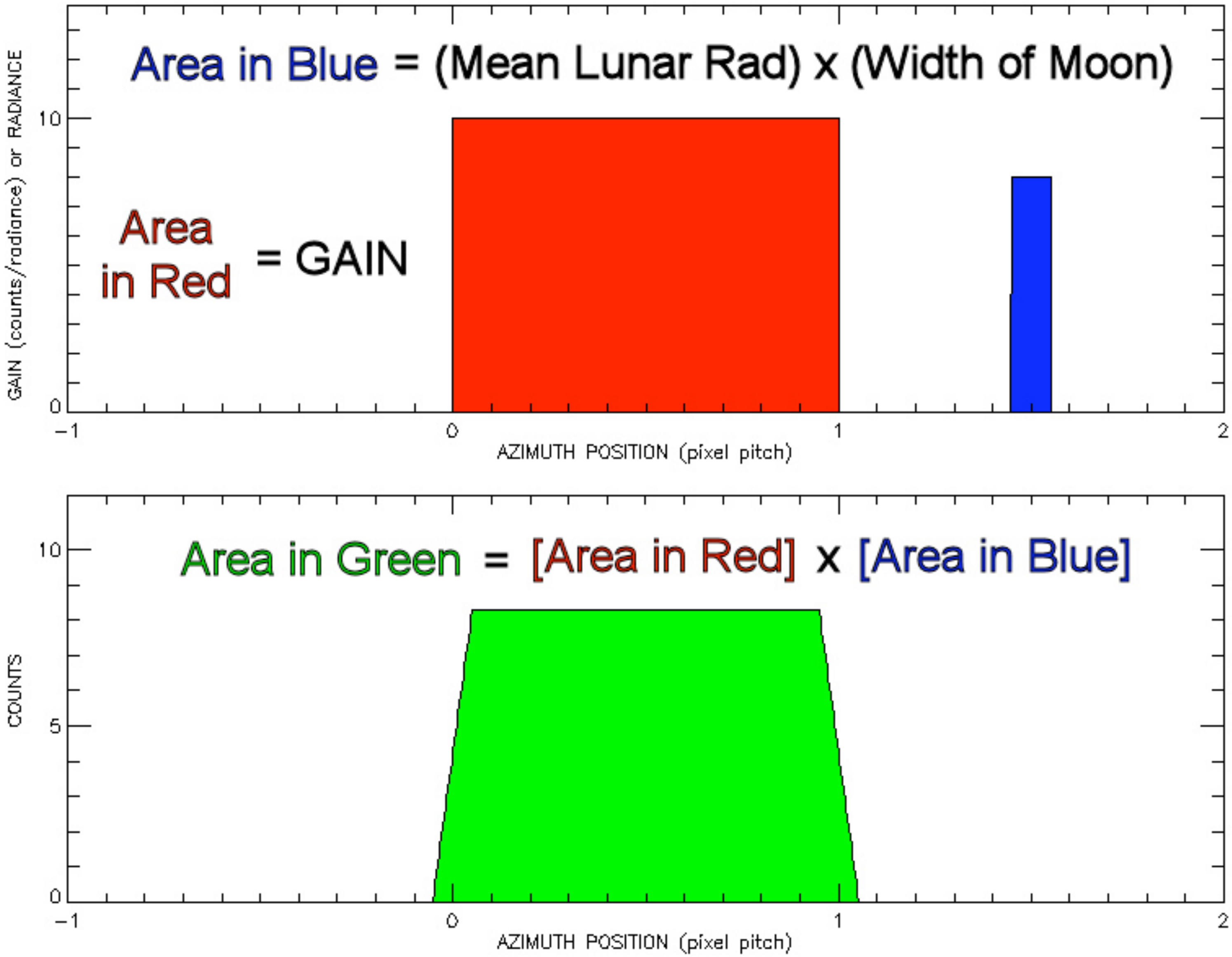

Azimuth Rotation at
fixed Elevation

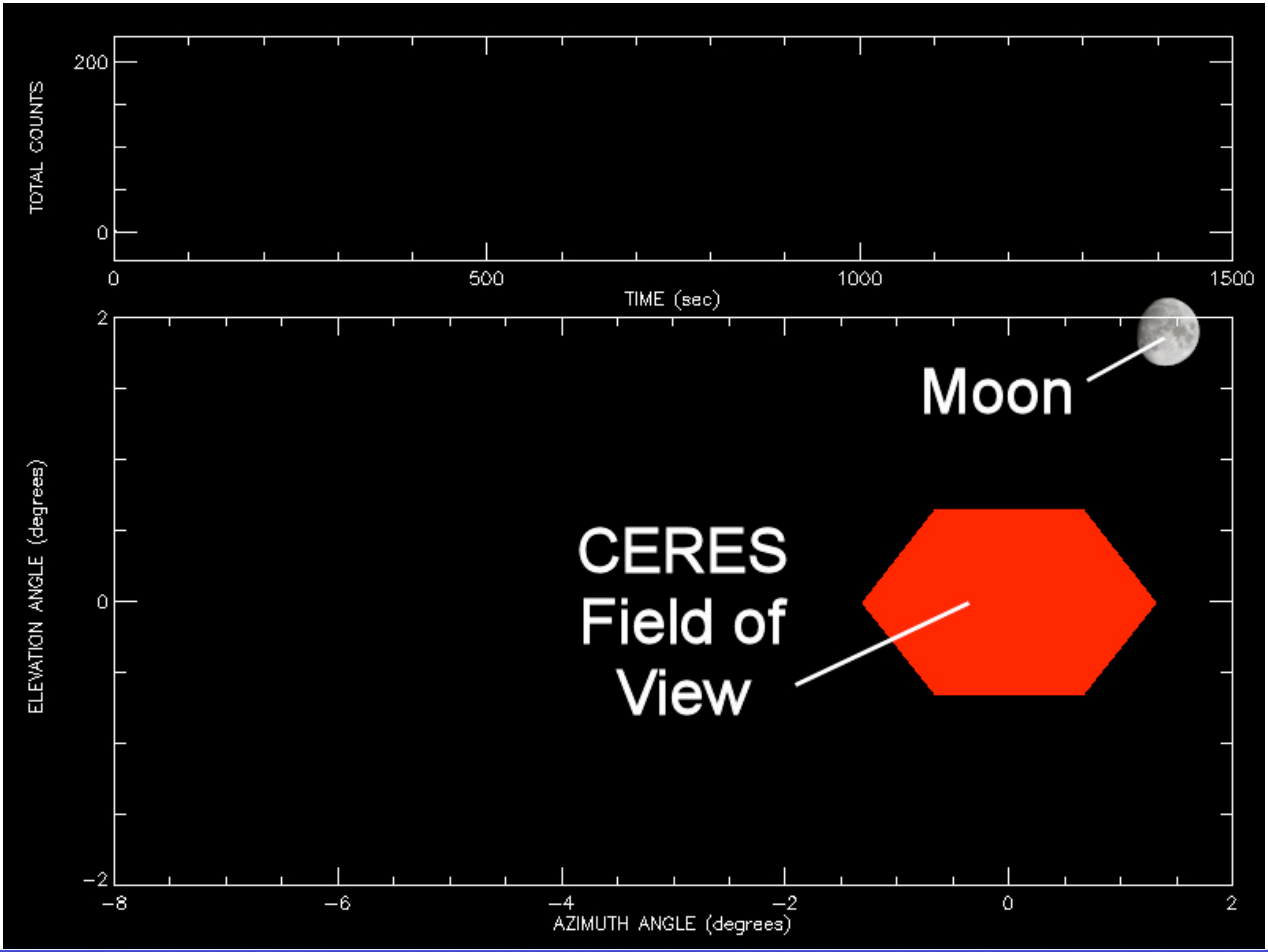

200
TOTAL COUNTS
0
0
10
20
30
40
50
TIME (sec)
2
Moon
CERES
Field of
View
ELEVATION ANGLE (degrees)
0
−2
−8
−6
−4
−2
0
2
AZIMUTH ANGLE (degrees)

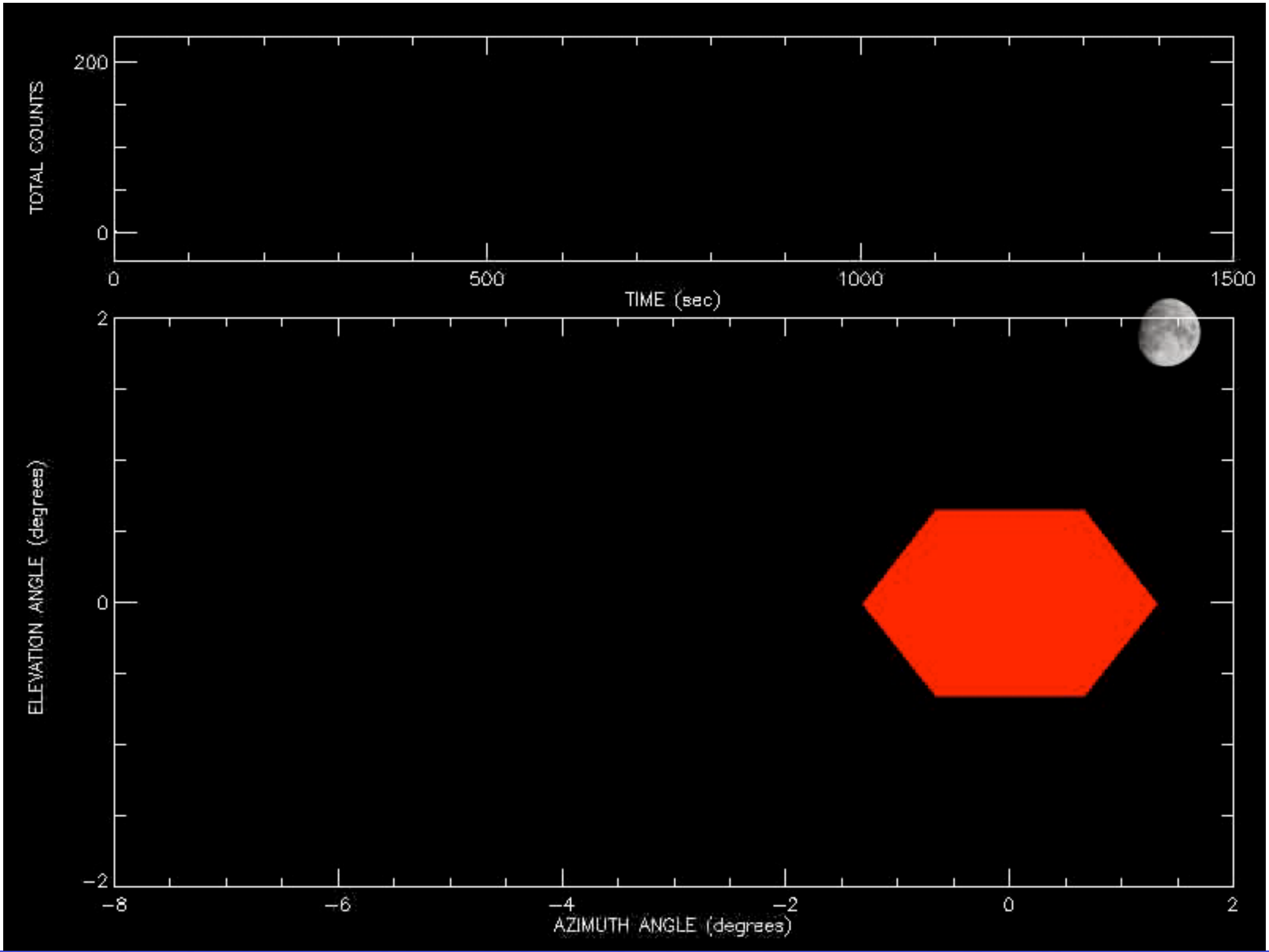

TOTAL COUNTS
200
0
0
10
20
30
40
50
TIME (sec)
ELEVATION ANGLE (degrees)
2
0
−2
−8
−6
−4
−2
0
2
AZIMUTH ANGLE (degrees)


GAIN (counts/radiance) or RADIANCE
10
0
-1
0
1
2
AZIMUTH POSITION (pixel pitch)
Example
Lunar Radiance
of 8 across 0.1
CERES pixel pitch
CERES PSF gives
10 counts per unit
of overfilling radiance
(i.e. GAIN=10)
COUNTS
10
5
0
-1
0
1
2
AZIMUTH POSITION (pixel pitch)

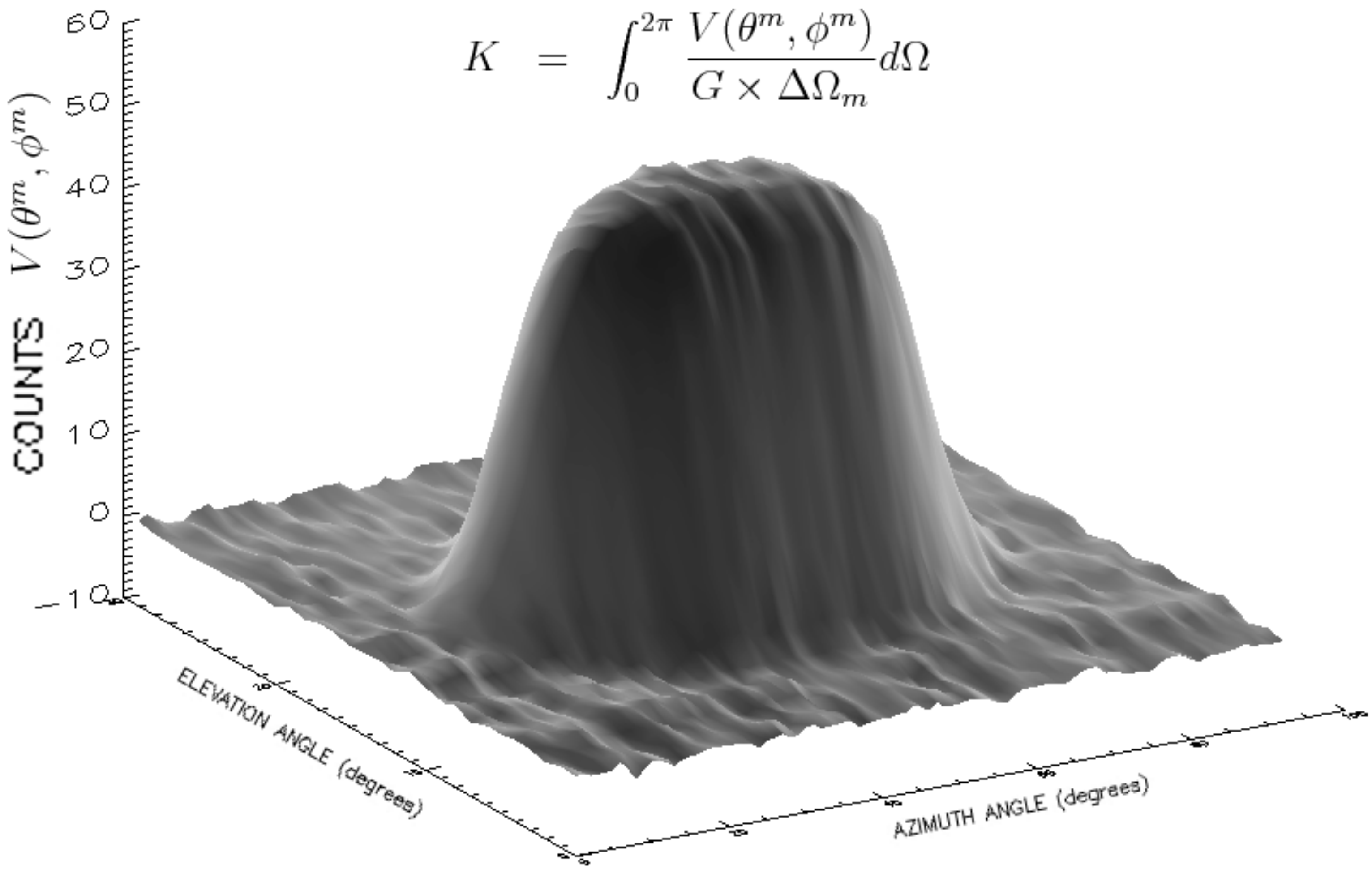

GAIN (counts/radiance) or RADIANCE
10
0
−1
0
1
2
AZIMUTH POSITION (pixel pitch)
COUNTS
10
5
0
−1
0
1
2
AZIMUTH POSITION (pixel pitch)

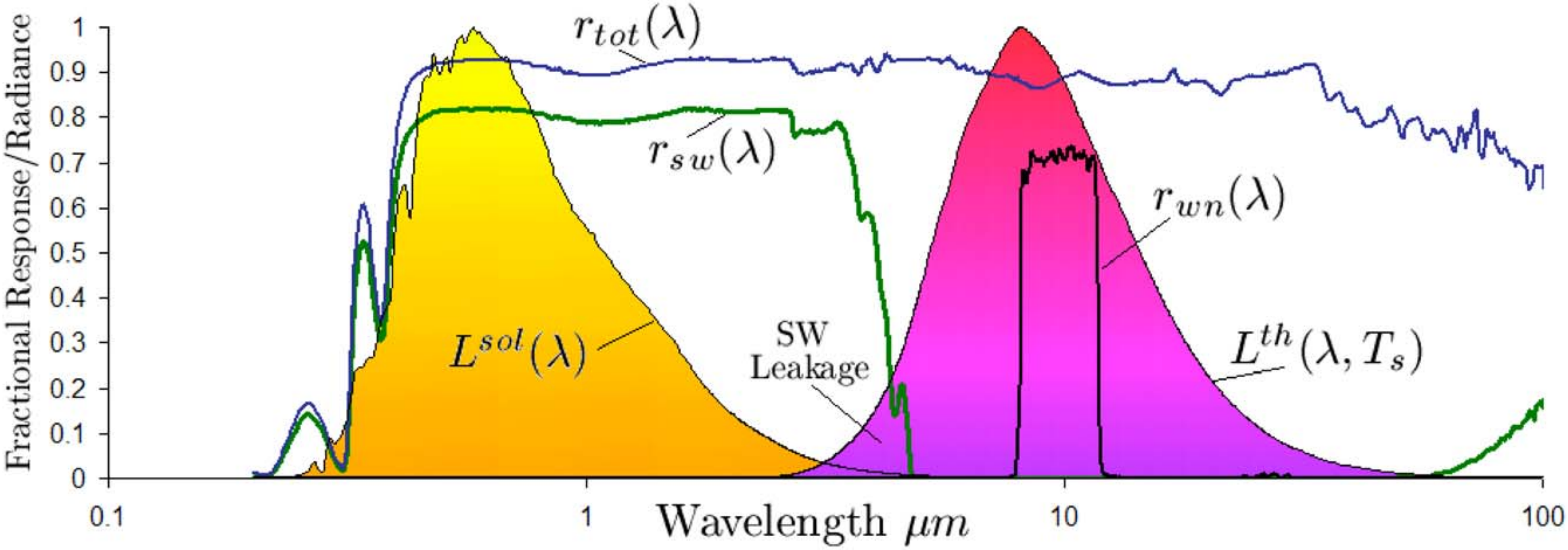

Area in Blue = (Mean Lunar Rad) x (Width of Moon)
Area in Red = GAIN
GAIN (counts/radiance) or RADIANCE
10
0
−1
0
1
2
AZIMUTH POSITION (pixel pitch)
Area in Green = [Area in Red] x [Area in Blue]
COUNTS
10
5
0
−1
0
1
2
AZIMUTH POSITION (pixel pitch)


TOTAL COUNTS
200
0
0
500
1000
1500
TIME (sec)
ELEVATION ANGLE (degrees)
2
0
−2
−8
−6
−4
−2
0
2
AZIMUTH ANGLE (degrees)
Moon
CERES
Field of
View


TOTAL COUNTS
200
0
0
500
1000
1500
TIME (sec)
ELEVATION ANGLE (degrees)
2
0
−2
−8
−6
−4
−2
0
2
AZIMUTH ANGLE (degrees)

$$K = \int_0^{2\pi} \frac{V(\theta^m, \phi^m)}{G \times \Delta\Omega_m} d\Omega$$





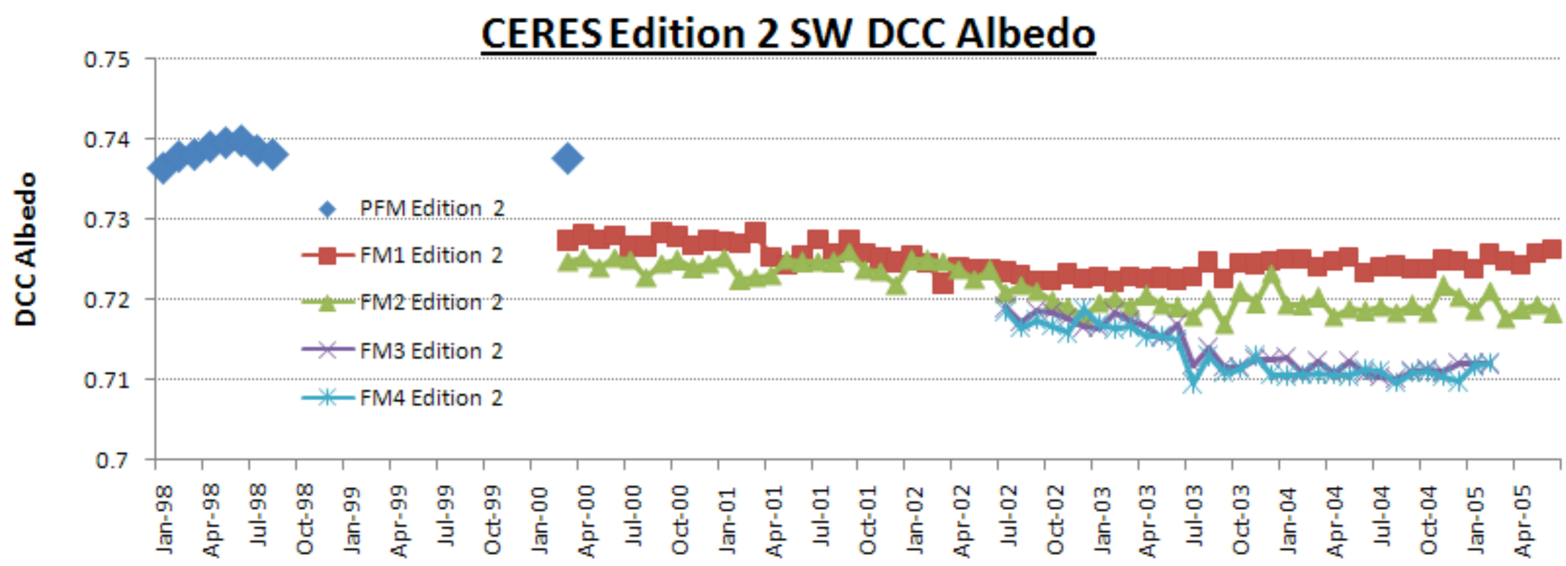

$$h_p = \frac{\pi \int_0^{200} L^{th}(\lambda, T_s^p) d\lambda}{\int_0^{200} r_{tot}(\lambda) L^{th}(\lambda, T_s^p) d\lambda}$$

$$d_p = \frac{\pi \int_0^{200} L^{th}(\lambda, T_s^p) d\lambda}{\int_0^{200} r_{wn}(\lambda) L^{th}(\lambda, T_s^p) d\lambda}$$

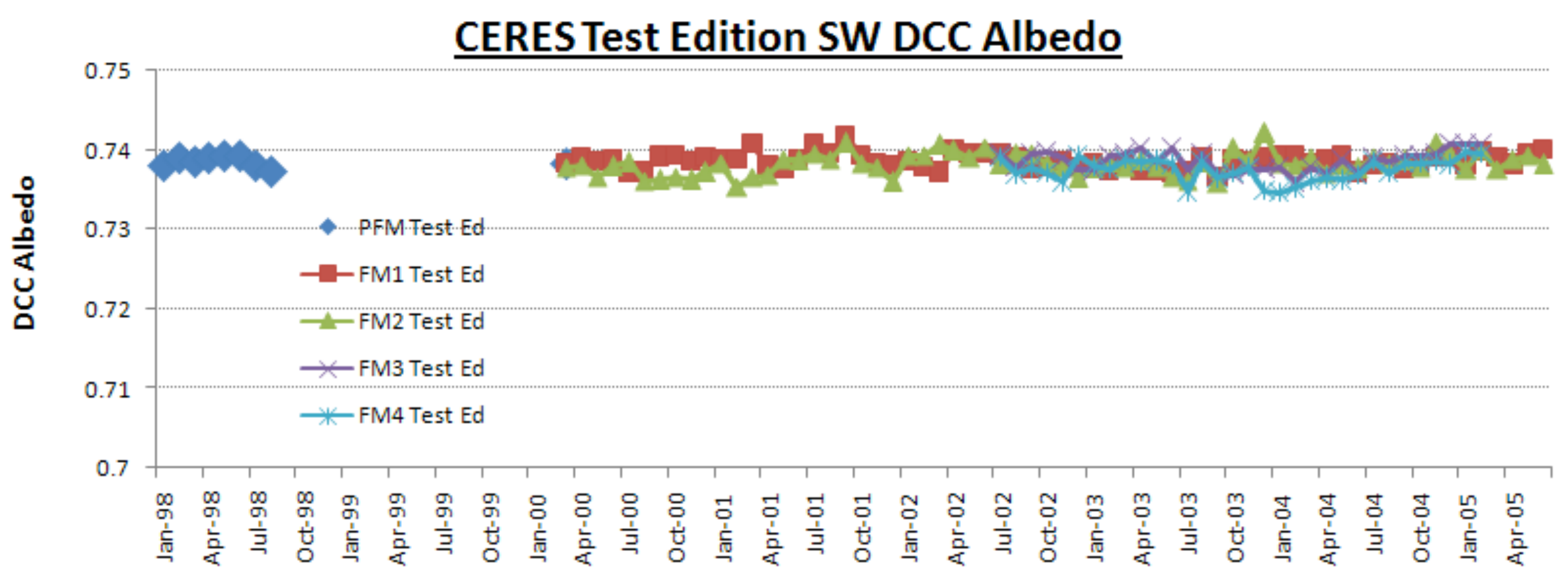
$$R_p^{SW} = \frac{\pi U_p}{W_p} \times \left( K_{sw}^p - \int_0^{200} r_{sw}(\lambda) L^{th}(\lambda, T_s^p) d\lambda \right)$$

$$R_p^{LW} = h_p \times \left( K_{tot}^p - \frac{\Gamma_p}{\pi U_p} \times R_p^{SW} \right)$$

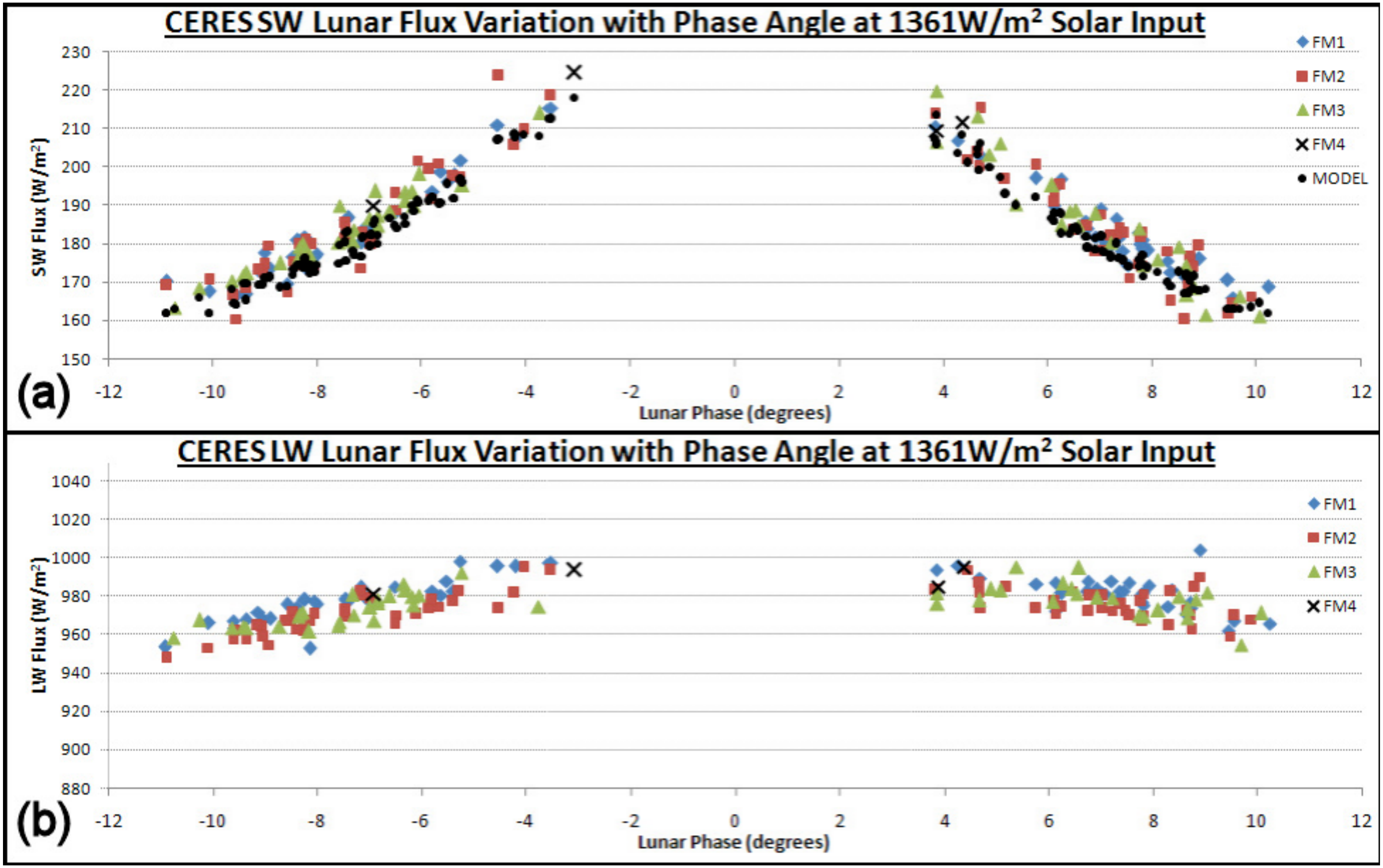
$$R_p^{WN} = d_p \times K_{wn}^p$$

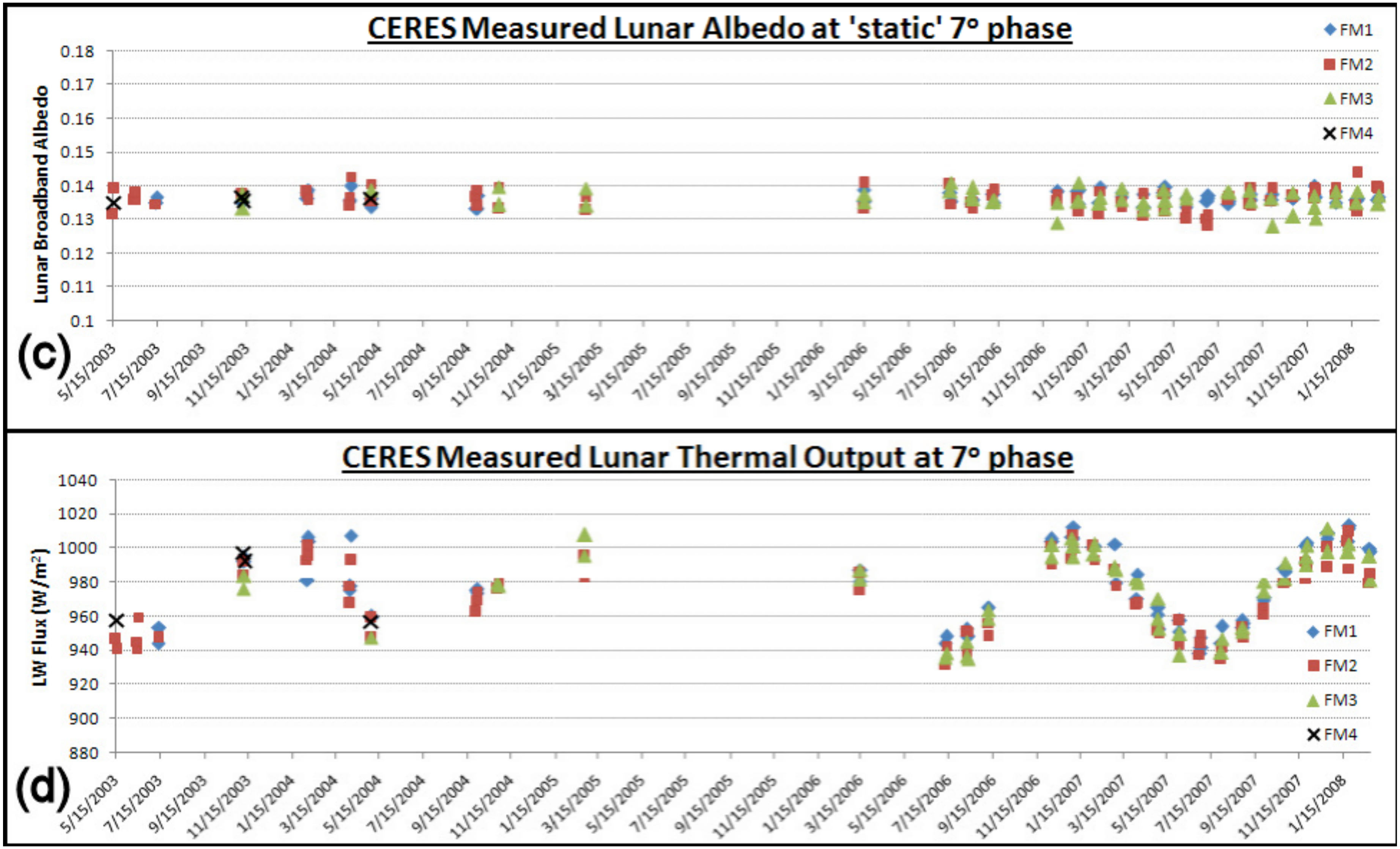


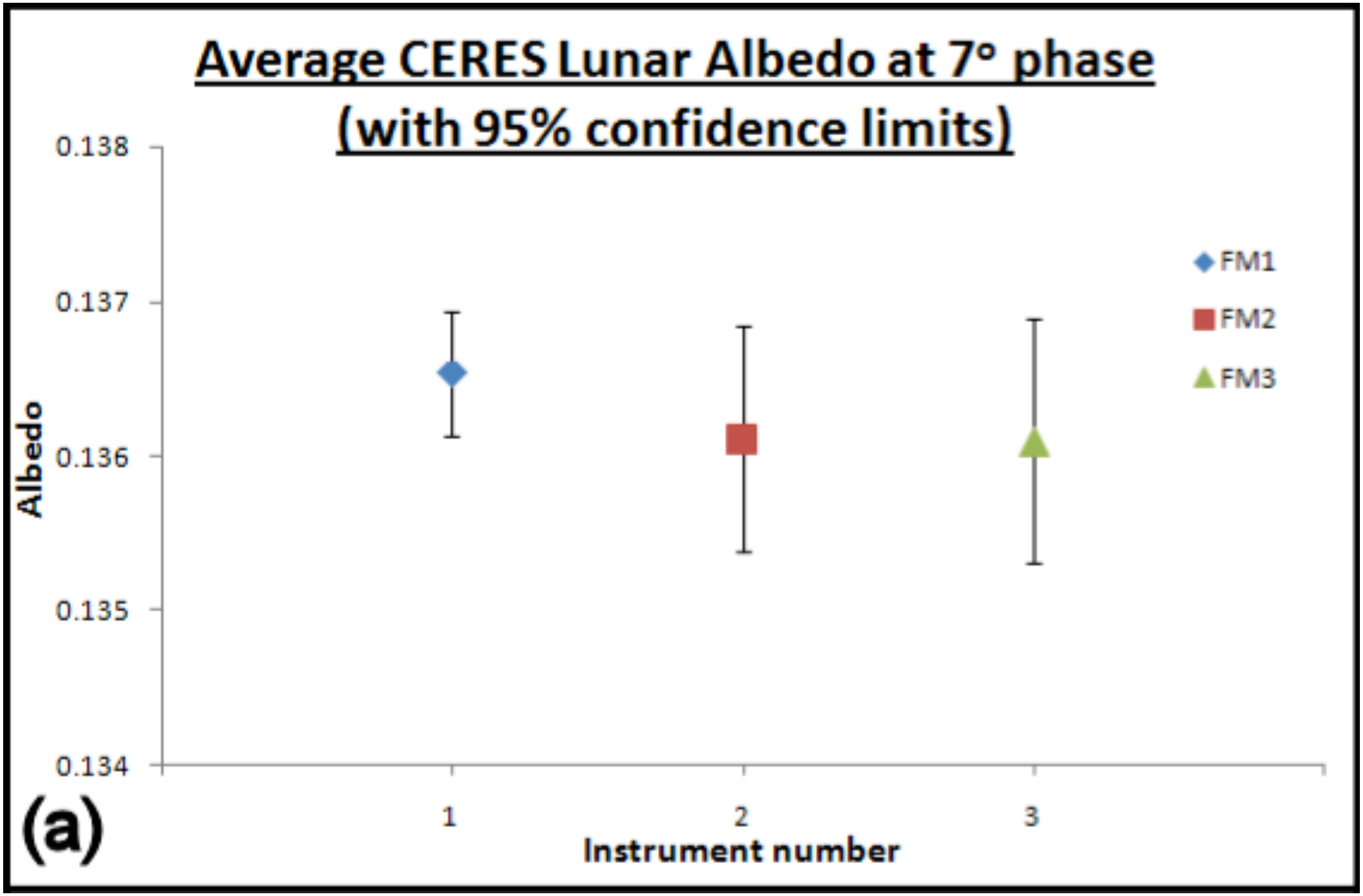
CERES Edition 2 SW DCC Albedo
DCC Albedo
0.75
0.74
0.73
0.72
0.71
0.7
PFM Edition 2
FM1 Edition 2
FM2 Edition 2
FM3 Edition 2
FM4 Edition 2
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Apr-01
Jul-01
Oct-01
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05

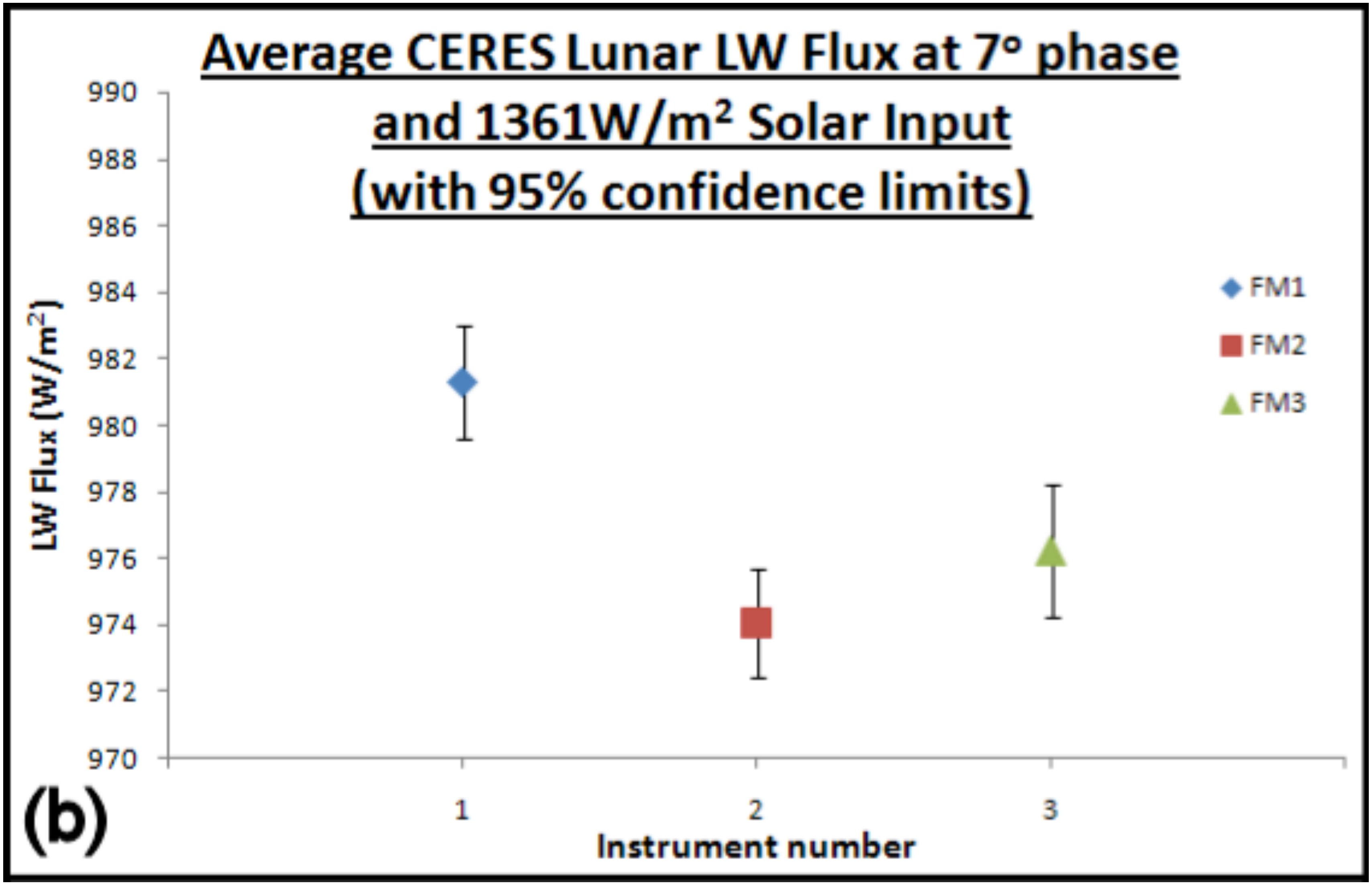



CERES Test Edition SW DCC Albedo
DCC Albedo
0.75
0.74
0.73
0.72
0.71
0.7
PFM Test Ed
FM1 Test Ed
FM2 Test Ed
FM3 Test Ed
FM4 Test Ed
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Jan-01
Apr-01
Jul-01
Oct-01
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05

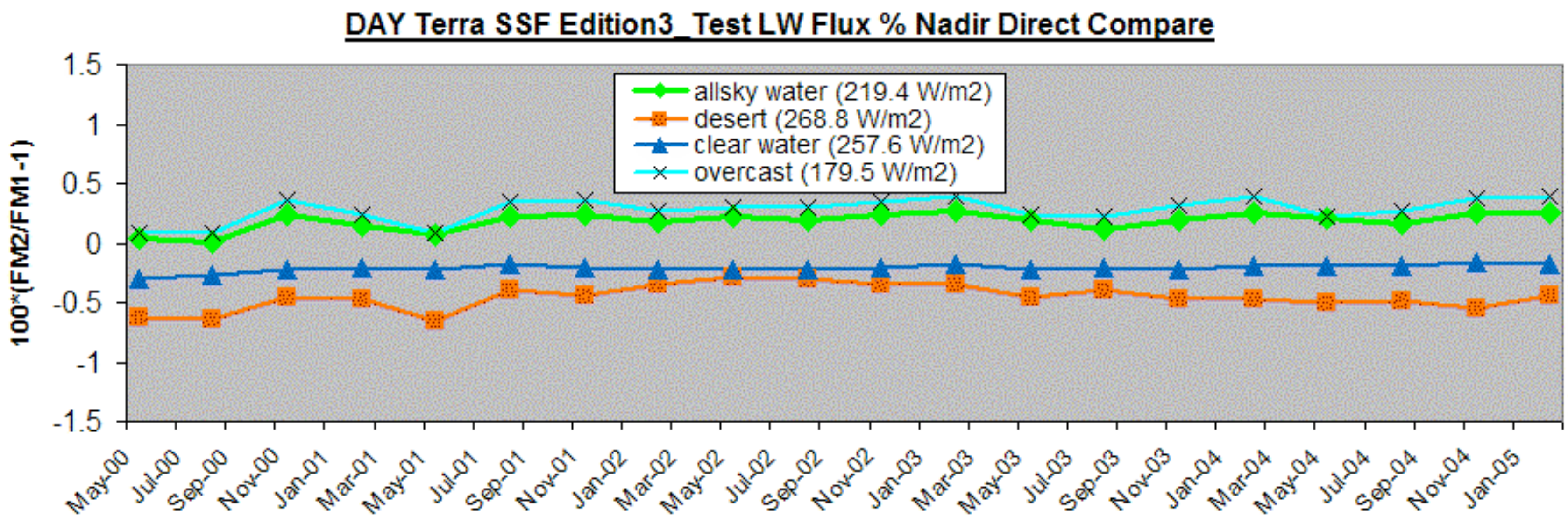

CERES SW Lunar Flux Variation with Phase Angle at 1361W/m² Solar Input
SW Flux (W/m²)
Lunar Phase (degrees)
FM1
FM2
FM3
FM4
MODEL
(a)
CERES LW Lunar Flux Variation with Phase Angle at 1361W/m² Solar Input
LW Flux (W/m²)
Lunar Phase (degrees)
FM1
FM2
FM3
FM4
(b)

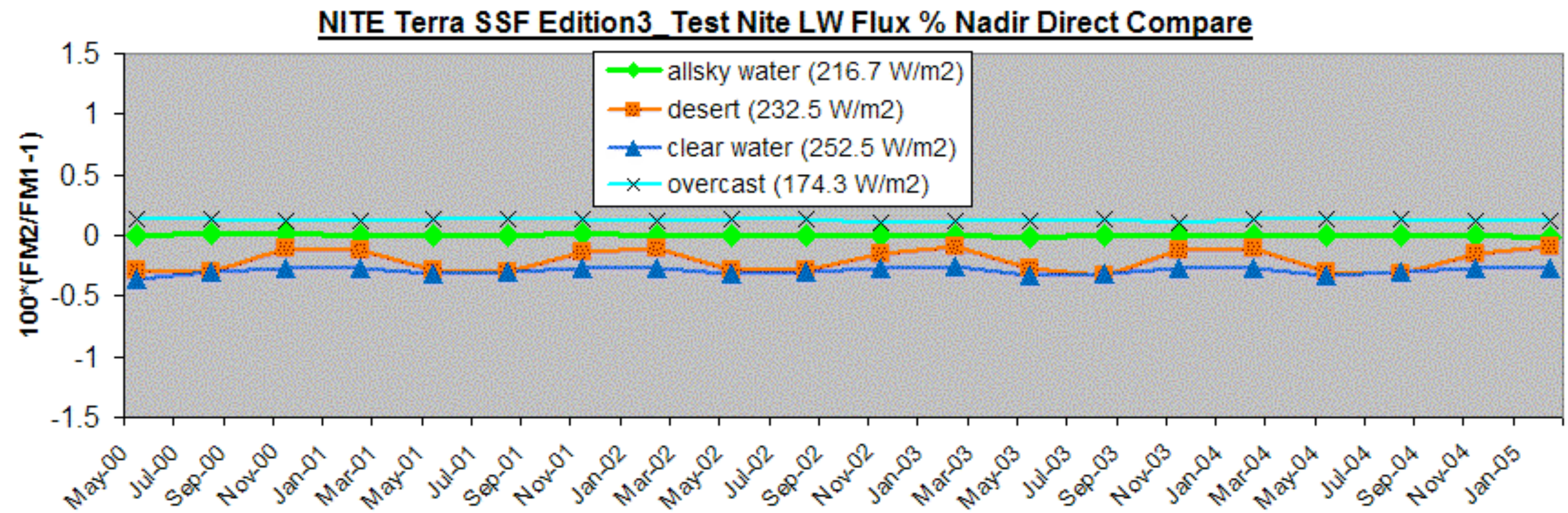

CERES Measured Lunar Albedo at 'static' 7° phase
Lunar Broadband Albedo
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
FM1
FM2
FM3
FM4
(c)
5/15/2003 7/15/2003 9/15/2003 11/15/2003 1/15/2004 3/15/2004 5/15/2004 7/15/2004 9/15/2004 11/15/2004 1/15/2005 3/15/2005 5/15/2005 7/15/2005 9/15/2005 11/15/2005 1/15/2006 3/15/2006 5/15/2006 7/15/2006 9/15/2006 11/15/2006 1/15/2007 3/15/2007 5/15/2007 7/15/2007 9/15/2007 11/15/2007 1/15/2008
CERES Measured Lunar Thermal Output at 7° phase
LW Flux (W/m²)
1040
1020
1000
980
960
940
920
900
880
FM1
FM2
FM3
FM4
(d)
5/15/2003 7/15/2003 9/15/2003 11/15/2003 1/15/2004 3/15/2004 5/15/2004 7/15/2004 9/15/2004 11/15/2004 1/15/2005 3/15/2005 5/15/2005 7/15/2005 9/15/2005 11/15/2005 1/15/2006 3/15/2006 5/15/2006 7/15/2006 9/15/2006 11/15/2006 1/15/2007 3/15/2007 5/15/2007 7/15/2007 9/15/2007 11/15/2007 1/15/2008

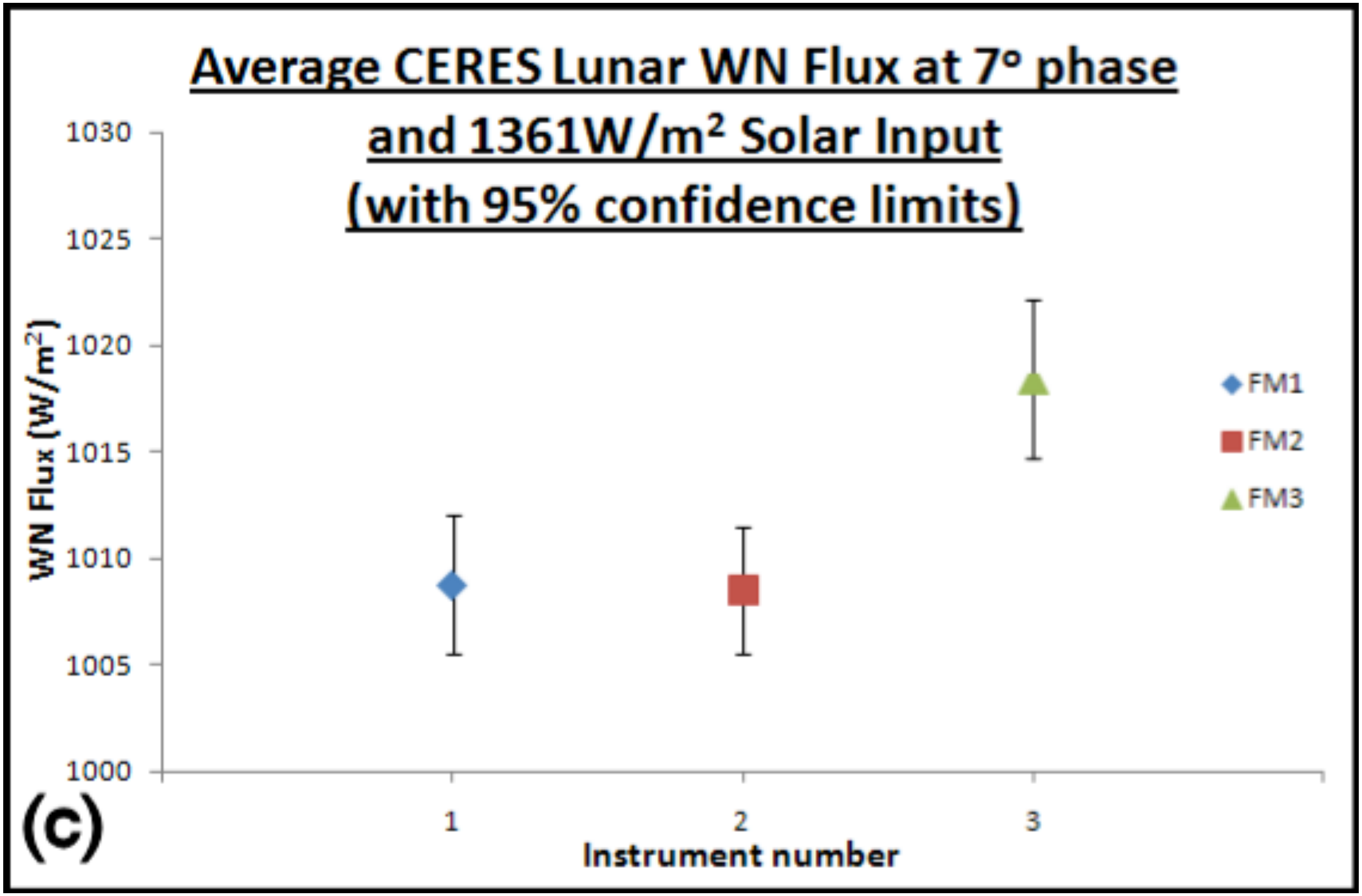

Average CERES Lunar Albedo at 7° phase
(with 95% confidence limits)
Albedo
0.138
0.137
0.136
0.135
0.134
FM1
FM2
FM3
1
2
3
Instrument number
(a)

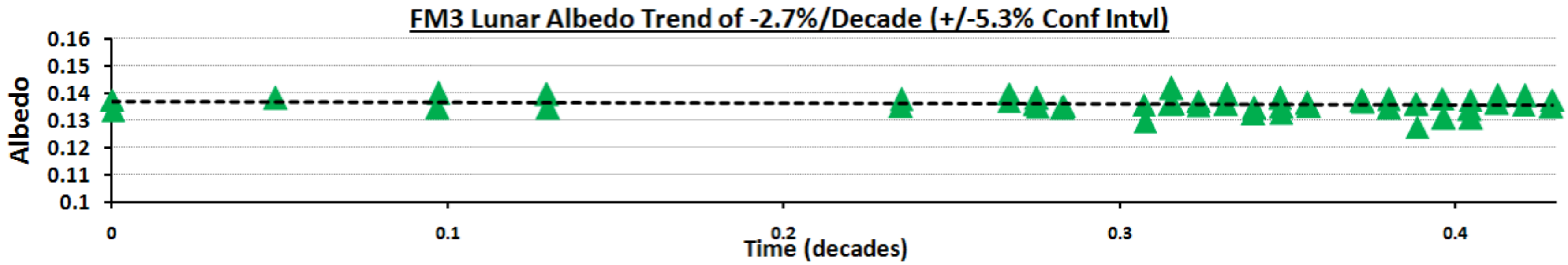

Average CERES Lunar LW Flux at 7° phase
and 1361W/m² Solar Input
(with 95% confidence limits)
LW Flux (W/m²)
990
988
986
984
982
980
978
976
974
972
970
FM1
FM2
FM3
1
2
3
Instrument number
(b)

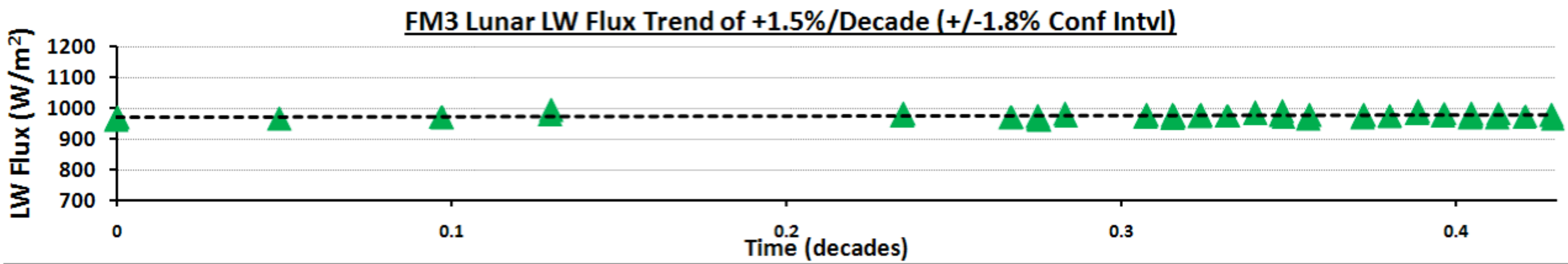
# SSF Edition3 Test run changes

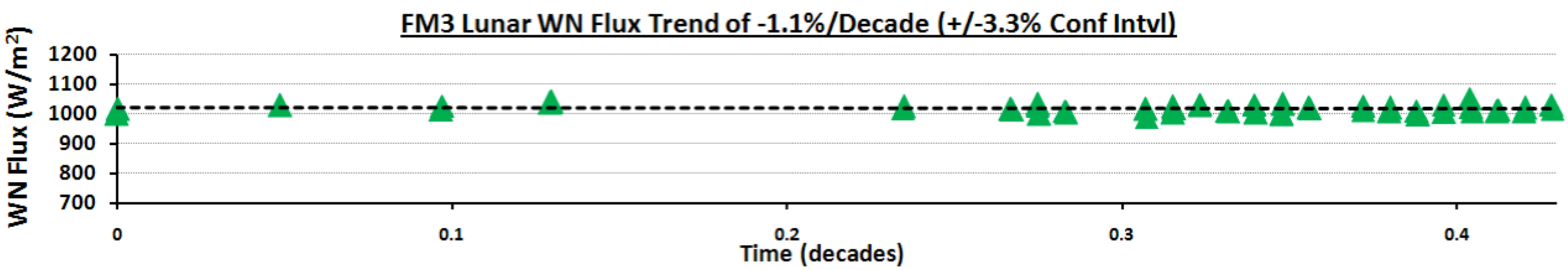



Average CERES Lunar WN Flux at 7° phase
and 1361W/m² Solar Input
(with 95% confidence limits)
WN Flux (W/m²)
1030
1025
1020
1015
1010
1005
1000
1
2
3
Instrument number
FM1
FM2
FM3
(c)


FM3 Lunar Albedo Trend of -2.7%/Decade (+/-5.3% Conf Intvl)
Albedo
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0
0.1
0.2
0.3
0.4
Time (decades)

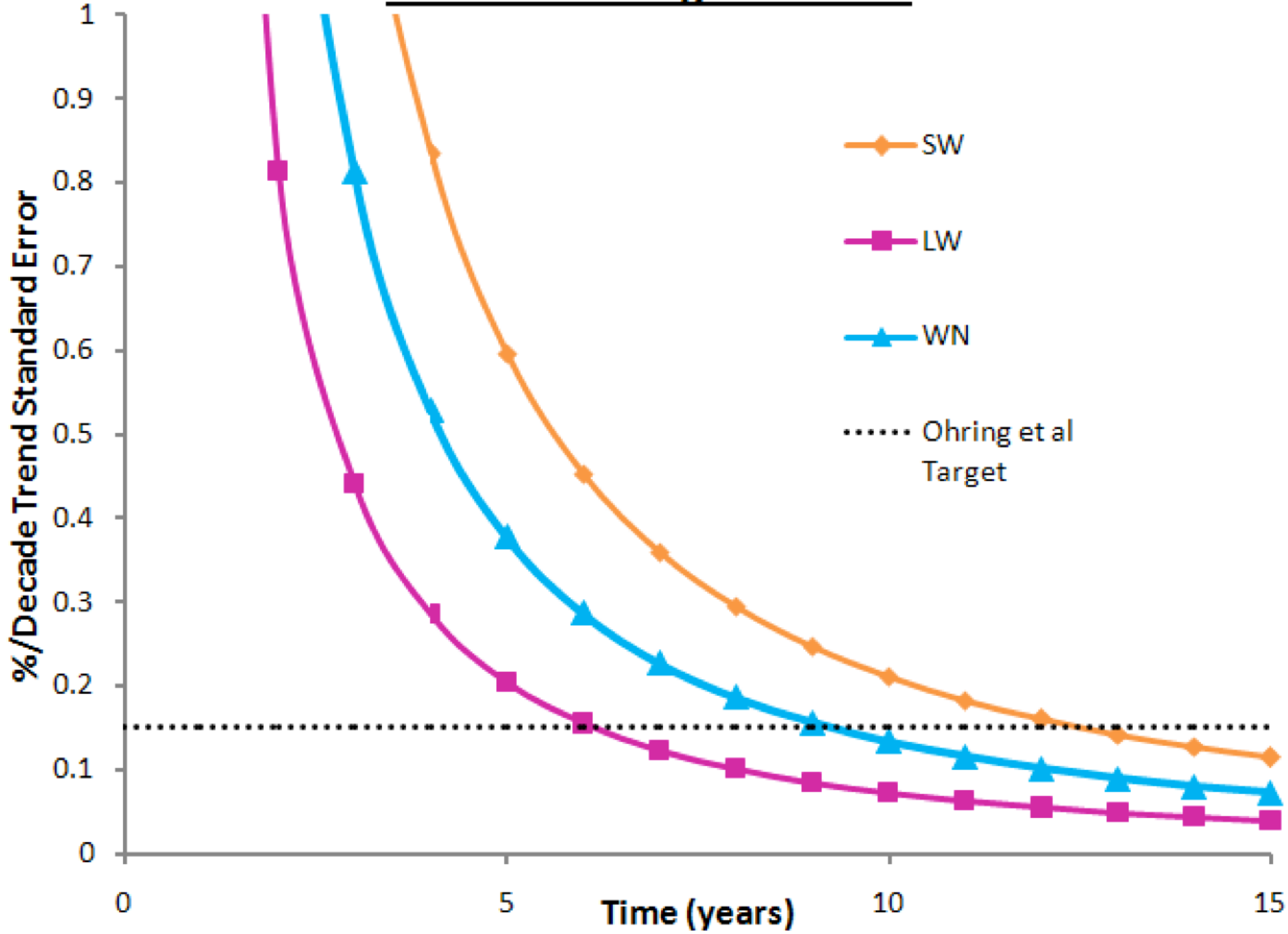

FM3 Lunar LW Flux Trend of +1.5%/Decade (+/-1.8% Conf Intvl)
LW Flux (W/m²)
1200
1100
1000
900
800
700
0
0.1
0.2
0.3
0.4
Time (decades)

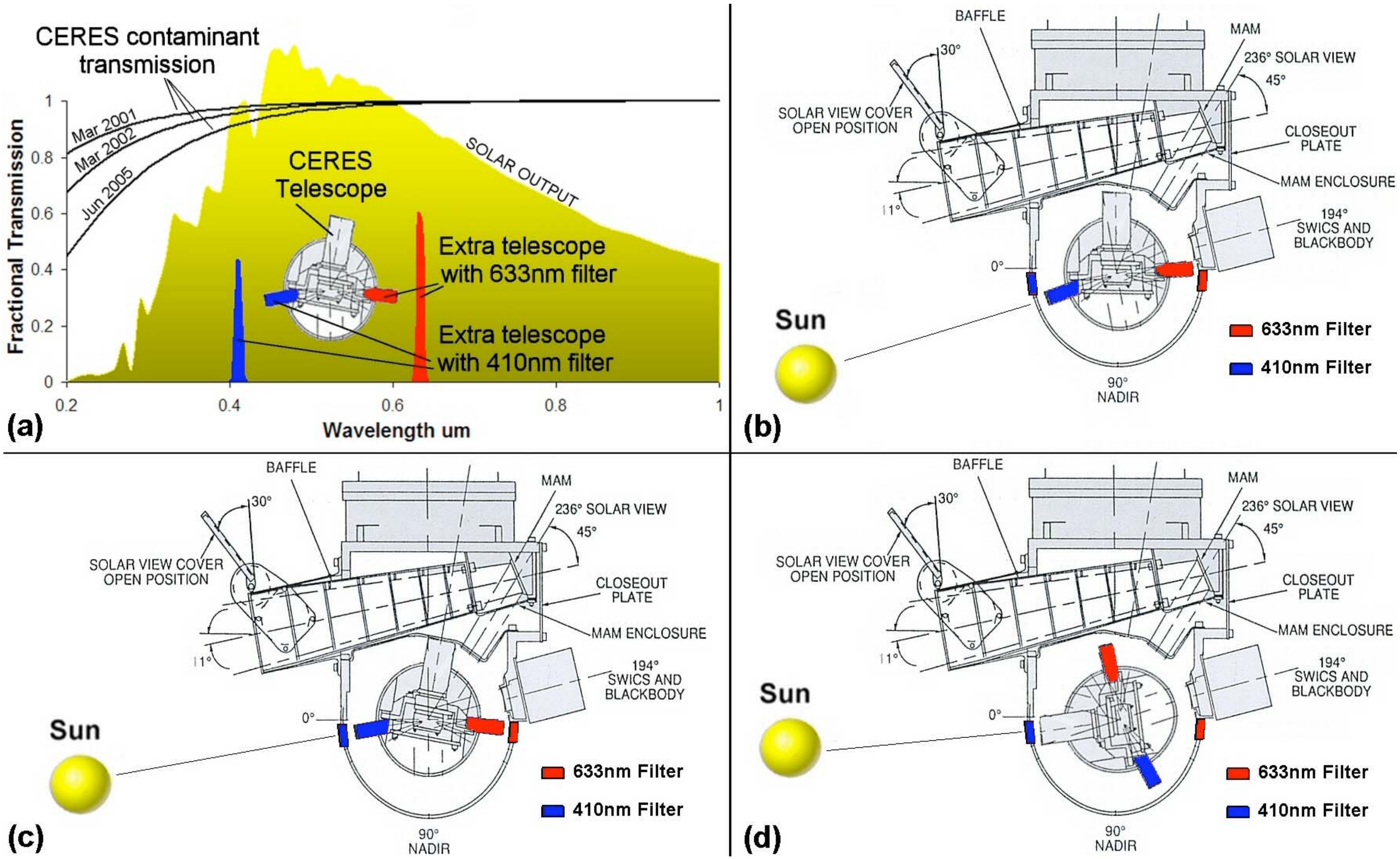

FM3 Lunar WN Flux Trend of -1.1%/Decade (+/-3.3% Conf Intvl)
WN Flux (W/m²)
1200
1100
1000
900
800
700
0
0.1
0.2
0.3
0.4
Time (decades)

Ohring et al (2005) suggests that ERB measurement stability needs to reach 0.3% per decade


This is near to an order of magnitude greater than CERES instrument design specification stability (note: not data products)

## Standard Error of CERES Climate Calibration Trends Measured using the Moon




CERES contaminant transmission
Fractional Transmission
1
0.8
0.6
0.4
0.2
0
Mar 2001
Mar 2002
Jun 2005
SOLAR OUTPUT
CERES Telescope
Extra telescope with 633nm filter
Extra telescope with 410nm filter
0.2
0.4
0.6
0.8
1
Wavelength um
(a)
BAFFLE
MAM
30°
236° SOLAR VIEW
45°
SOLAR VIEW COVER OPEN POSITION
CLOSEOUT PLATE
MAM ENCLOSURE
11°
194° SWICS AND BLACKBODY
0°
Sun
633nm Filter
410nm Filter
90° NADIR
(b)
(c)
(d)

# Summary

- CERES (PFM SW scale) measures the Lunar Albedo to be **0.1362** (+/- 2-3%), all instruments agree on this figure within confidence giving validation to DCC unity technique.

- CERES measures the Lunar LW Flux to be **977W/m$^2$** (+/- 2-3%)

- LW ERB Ohring target reachable in **6 years** using the Moon

- SW ERB Ohring target reachable in **12 years** using the Moon (0.3%/decade 1σ reachable in **8 years**)

- Technique can be used with over and under-filled telescopes e.g. imagers/CLARREO and CERES-II with the Sun